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Parameter Optimization of Used Oil Fired Small Sized Crucible Furnace for Melting Aluminium in Small Scale Local Foundry Workshops

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Abstract

Energy is one of the key important input factor in the foundry industries require new combustion concept for effective utilization of the fuel with controlled emission. Foundry technology mainly requires furnace for melting the metal to be casted. Melting energy and pollution are the most important factor while using furnace for melting. The main problem of the furnace was observed in consistent Efficiency. Hence, the existing furnace needs to optimize for effective utilization of fuel, melting time, environmental pollution and reduction in safety hazards while melting. Controlling combination of seven selected variable parameters was the method which uses to optimize performance of the local existing furnace which results complete combustion. While optimizing the furnace it need to survey the existing furnace, identify the effect of each parameter then optimize it based on design of experiment (DOE) result and regression analysis using genetic algorithm. Based on the experimental result and Genetic Algorithm optimization tool, improvements using the selected seven parameters has been observed at (3100rpm of air blow rate, 3.032ml/s of fuel drop rate, 35.2000 degree of inclination angle of fuel runner, 35.100 degree of inclination angle of air runner, 60.090mm clearance between wall of the furnace and crucible, 8.500mm of position of fuel and air mixture beyond80.050mm of diameter of fuel and runner mixture. The study shows particularly fuel consumption for 30kg, 35kg and 40 kg of aluminium requires 6.830 litters, 7.014liters and7.120 litters respectively. According to this study fuel can be saved up to 54% and hence, effective combustion will be occurred and pollution will be reduced while melting. Moreover, as the amount of aluminium scrap to be melted increases, efficiency of the furnace increases significantly.

Key words: Energy, Furnace, foundry, Efficiency, DOE, ANOVA, Genetic algorithm

Introduction

Background

Energy is one of the main input factor in the foundry industries require new combustion concept for effective utilization of the fuel with controlled emission. Foundry is a factory that produces metal casting from liquid metal without intermediate operations of mechanical work and can also create simple to complex geometries. Foundry technology mainly requires furnace for melting the metal to be casted. There are different types of furnaces available in foundry workshops which are used to melt non-ferrous metals such as electrical furnace, oil fired furnace, butane fired furnace and using coke. From the above mentioned types of furnaces, the most popular furnace usually used in our local SME is oil fired crucible furnace. Used oil is becoming a common heat source for many applications because it can reduce the energy cost significantly. Besides, used oil is inexpensive as compared to conventional fuels and also readily available in garages and oil change service centres Binoy, C.(2008). Ethiopian Environmental Protection Agency (EPAE) and several researchers encourages the proper collection, storage, treatment and reuse of this waste oil, in addition to its environmental benefits the application of used oil in furnaces offers high calorific value that makes it a good alternative fuel Furthermore, such fuels obtained from wastes save significant costs of energy in such low capital workshops EPSE,(2015).

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In oil burners, oil is atomized in to a fine spray by controlling combustion of air to fuel ratio Gupta, R. (1989). The used oil furnace uses standard electrical blower to atomize oil for burning. However, SMEs (in Mekele city) that use used oil for combustion often raise concerns about inconsistency in fuel consumption and melting time variation during utilization of these waste oils. There are many variables involved in the supply of the used oil fuel to the furnace. The factors are interrelated to each other and can affect the efficient utilization of energy. In this study the parameters for melting aluminium in foundry workshops are selected based on selection criteria that can affect efficiency of the furnaces. The selected seven parameters for design of experiment are: air Blow rate (ABR), fuel drop rate (FDR), inclination angle of fuel runner (IAFR), inclination angle of air runner (IAAR), clearance between wall of the furnace and crucible(CWC), position of fuel and air mixed (PFA) and diameter of fuel and Air mixed orifice (DFAM).

Preliminary discussion and reports/ feedbacks from SME foundry shops indicate that efficiency of the furnace in used oil utilization is inconsistent. This causes to consume fuel, time safety hazards while melting and casting defects. Therefore, there is a need to optimize the melting parameters in these used oil fired crucible furnaces for melting non-ferrous metal to improve furnace efficiency. Energy optimization is the most important input factor in the thermal industries that require alternative fuel for effective utilization of energy (Musa N., 2012).Therefore, the thesis deals with parameter optimization of used oil fired small sized crucible furnace taking highly applicable engineering material Aluminium's a typical nonferrous metal in controlling parameters using Genetic Algorithm tool.

Statement of the Problem

From a survey of local SME foundry workshops that uses used oil for melting, the efficiency of crucible furnaces is not consistent. Fuel consumption varies up to 54% wastage to melt 30kg-40kg aluminium scrap; variation in melting time and as well as it causes pollution. As a result, the furnaces operate with varying energy efficiency that leads to produce defected castings, high un necessary cost, hazardous during melting. This indicates there is a need for parameter optimizing used oil fired crucible furnace to utilize used oil as alternative fuel and get high calorific value. Such waste reuse practices also save foreign currencies besides to other economic benefits.

Methodology

Crucible Furnaces Characteristics

According to Osarenmwinda, J.(2015) crucible furnace is one of the oldest and simplest types of melting unit used in the foundry. The furnace uses refractory crucible cylindrical container that can withstand a very high temperature and good thermal conductor. The charge is heated through conduction of heat in the walls of the crucible. The heating fuel is typically coke, oil, gas or electricity. Crucible melting is commonly used where small batches of low melting point alloys are required. One of the most widely used furnaces is the oil fired crucible furnace which uses the combustion of oil as a fired source to heat the crucible and melt the solid metal inside it. Some of the advantages of oil fired crucible furnace are low investment costs, easy operation and maintenance ability, capable of melting small batches of various alloys.

Importance of Furnace on Casting Process

A metal casting may be defined as a metal object produced by pouring molten metal into a mold containing a cavity which has the desired shape of the end product and allowing the molten metal to solidify in the cavity Richard,W. et al.(1997). Castings have several characteristics that clearly define their role in modern equipment used for transportation, communication, power, agriculture, construction and industry. Cast metals are required in various shapes and sizes and in large quantities for making machines and tools, which in turn work to provide all the necessities and comforts of life. Other metal shaping processes, such as hot working, forging, machining, welding, stamping are of-course necessary to fulfil a tremendous range of needs. However, according to Jain certain manufacturing process inherent in casting design and metallurgical advantages; thus it endow themselves superiority over other methods Jain, p. (2003).

Foundry technology mainly requires furnace for melting the metal to be cast. One of the most popular furnaces in SME is oil fired crucible furnace. In oil burners , Gupta, R.(1989) defined as oil is atomized in to a fine spray by controlling combustion of air to fuel ratio with spray nozzle as shown in the Figure 2.1. The used oil furnace uses standard electrical blower to atomize oil for burning. Furnaces are heating technologies that use air supplied and integrated with the combustion of a fuel oil. Over the past century, these technologies have continually changed for different fuel applications, along with the variations and choices it needs optimization EPAE, (2004).

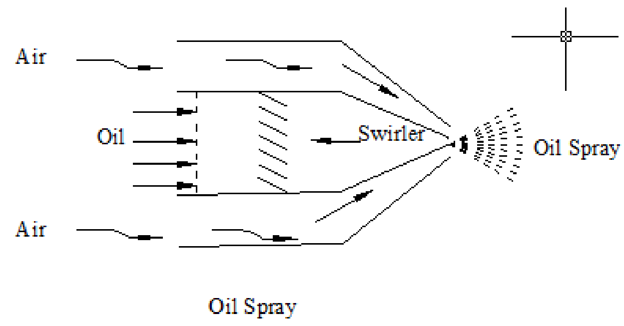


Figure 2.1 Oil Spray Mechanism

Source: adopted from Gupta,R. (1989)

Effect of Melting Temperature on Casting Quality

The quality of cast products directly depends on the quality of molten metal from which the products are cast. Comprehensive understanding of the melt quality is vital importance for the control and prediction of actual casting characteristics. Any defect added or created during the melting stage will be carried to the final microstructure and certainly affect the quality of cast products. Therefore it is apparent that the control of the quality of the cast products begins with the control of the quality of the meltMile B. (2010).

Casting defect is an undesired irregularity in a metal casting process. Some defects can be tolerated while others can be repaired, otherwise they must be eliminated. There are many types of defects which result from many different causes. Some of the solution to certain defect can be the cause for another type defect. Peter, B. (2001). According to Rajish, R. and Jaweed, K. (2014) mostly casting defects are concerned with process parameters and melting temperature that determines casting quality. Casting defects are divided in to four main categories: filling related defect, shape related defect, thermal defect and defect by appearance Rajish, R. et al.(2014).

Furnace Oil Characteristics

Viscosity is one of the more critical properties of oil. It refers to its resistance to flow. The Society of Automotive Engineers (SAE) standard oil classification system (SAE J300) categorizes oils according to their viscosity (via a number system such as SAE 10W, SAE 30, SAE 15W40, etc.)Jain,A.(2006).

Kinematic viscosity is graded by measuring the time it takes for a standard amount of oil to flow through a standard orifice, at standard temperatures. The longer it takes, the higher the viscosity and thus higher SAE code. Viscosity is defined as the resistance to flow of a liquid deformed by shear stress. It describes a liquid's internal resistance to flow and may be thought of as a measure of a liquid friction. A liquid lubricant between two horizontal plate and solid bodies, one fixed and one moving with a constant speed. Kinematic viscosity is often used to specify lubricants. One reason is that the kinematic viscosity is easier to measure. The kinematic viscosity is independent of the density. Kinematic viscosity is measured by allowing the lubricant to low through a capillary with a defined diameter only affected by the gravity. The time for a certain amount of lubricant to low thorough the capillary is measured. The set-up is known as a capillary viscometer. Willey, (2014)

Effect of Pressure on Viscosity

The lubricant viscosity increases with increasing pressure. In most cases the lubricant compressibility is not important, but in some dynamic sequences it may be crucial Schlosberg,R Chu, J. Knudsen, G. Suciu E. and Aldrich, H.(2001).

Effect of Temperature on Viscosity

Viscosity of liquids decreases with increasing temperature and, consequently, the lubricating oil becomes thinner as the operating temperature increases. Hence, viscosity of good lubricating oil should not change much with change in temperature, so that it can be used continuously, under varying conditions of temperature. The rate at which the viscosity of lubricating oil changes with temperature is measured by an arbitrary scale, known as Viscosity Index (V. I). If the viscosity of lubricating oil falls rapidly as the temperature is raised, it has a low viscosity index. On the other hand, if the viscosity of lubricating oil is only slightly affected on raising the temperature, its viscosity index is high Schlosberg,et.al.(2001).

Performance Improvement of Crude Oil Fired Furnace

Energy is one of the important crucial input factor in the thermal industries require new combustion concept for effective utilization of the fuel with controlled emission. Due to the reduction of fossil fuels at alarming rate and increasing of pollution levels from the various combustion process such as I.C engines, boilers and furnaces, the need arises for the evolution of the new combustion techniques by comparing with the existing combustion techniques. The increased consumption rate of petroleum and crude oil price leads to the usage of alternate fuels or newer technological development. Furnace operating below optimum efficiency and emission levels can be improved by new technological approaches by retrofitting in new system. Oscillating combustion is relatively a simple process. It is accomplished by introducing an oscillating digital valve on the path of the fuel line. The oscillations are introduced by the valve which operates at different amplitudes and oscillating frequency. The effect of these oscillations is increased heat transfer to the load which results in low fuel consumption, increased production rate and improves furnace efficiency. Oscillating combustion methodology for overall improvement performance of an aluminium foundry furnace was taken up. Overall improvement effectiveness of an oil fired furnace which is a metric for total productive maintenance initiative has been calculated the results of the experiments lead to significant saving in fuel consumption, huge reduction in Nox emission in highly cost effective manner; which results in revenue savings. The objective of the research work was a demonstration of the "oscillatory combustion technology" on a diesel fired crucible furnace to melt aluminium for process operations.

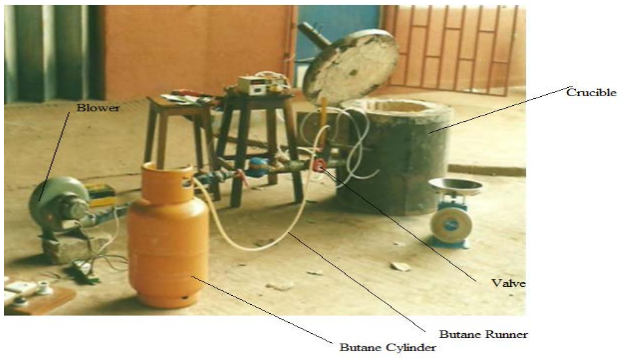
Oscillating combustion valve was installed in the testing furnace as retrofit and carried out experiments to study the performance of the oil fired crucible furnace at different combustion modes through the study of different output parameters (such as melting time , fuel consumption, heat transfer rate) and also through visual observations of various flames and emissions. The experimental results obtained using the test stand of oscillating valve in the furnace are very promising. The main conclusions that were drawn:-

According to Aditya,N and Ramana,R. (2012) there is an increase in furnace efficiency and Fuel saving in the oscillating combustion mode depending up on the condition, there is a huge increase in efficiency for all loads during the oscillating combustion modes. The melting time observed with oscillating combustion operation is lower than the non-oscillating. The maximum efficiency, minimum fuel consumption and melting time of the stock are observed at oscillations at minimum frequency. With all the above characteristics, the concept of oscillating combustion technology is superior to the standard study state combustion technology currently being used in the heat transfer industries in terms of both energy efficient and consequential fuel cost saving as well as significantly helps to reduce pollutant emissions Aditya,N et.al, (2012).Weakness and strength of performance improvement of an oil fired furnace through oscillating combustion technology has been summarized on table 2.2

Table 2.1 Comparison of Crude Oil with Used Oil Fired Crucible Furnace summary

Strength	Weakness
Energy consumption was improved through oscillation technology with controlling parameters	It consumes crude oil which is expensive. Initial costs of the furnace were expensive since the machine has incorporated with expensive components like digital fuel valve regulator.

Source: Aditya, N et.al. (2012).



Energy Utilization and Pollution

Several researchers have studied that conversion of waste oil to energy is one of the recent trends in minimizing not only the waste disposal but also could be used as an alternate fuel for industries Binoy,C. (2008).Nowadays, waste management has gone a step further not only on planning proper disposal schemes but also on attempting to see whether there are possibilities of reusing and recycling certain materials and turn out energy from waste matter. Peculiarly, the management of oil pollution will possibly be a potential threat as the general trend of used oil generating facilities in the region are significantly increasing. Hence, there is a real need to reduce both the cost and environmental impacts arising from the generation and disposal of wastes in all oil waste generating settings. Recently some small enterprises at recoup markets in Mekelle city are generating energy from used oils .

Optimization Using Genetic Algorithms

Genetic algorithms (GA) inspired by Darwinian Theory, represent powerful non-deterministic iterative search heuristic Al-Duwaish, et.al.(2001). Genetic algorithms operate on population consisted of encoded strings, where each string represents a solution. This algorithm uses the crossover operator in order to obtain the new solutions. Like in humans, the new generation of the solution inherits properties from its parent solutions, both good and bad properties. Each solution from the set has its own fitness value. This value represents a merit that defines the likeliness for surviving in the next generation. It is essential for these algorithms to produce new properties in the next generation. For that purpose the mutation operator is used. This procedure is iteratively repeated until it derives a solution that satisfies some norm or the run time exceeds to some threshold. To apply this idea to an optimization problem, a first generation is composed of a set of points in the optimization domain. After that a chromosome is defined for each of these points. When the algorithm starts to work iteratively in order to obtain new (and better) population, a genetic operator is applied to the chromosomes. Usually, when optimization is the problem, the algorithm chooses the chromosomes with the best evaluation function. These chromosomes have more probabilities to be selected from the chromosomes of the current population. The selected elements are part of the mating, crossover and mutation processes. For detailed reading on genetic algorithms the reader may refer to Goldberg,(1989). Also I would like to recommend some other texts for further reading such as Mitchell,(2008), Konak et al. (2006), Poli et al.(2008) and Weise,(2009) that are considering optimization using genetic algorithms form different aspects. One of the first papers about the genetic algorithms for optimization of MPC was presented by Onnen et al. (1997) and Blasco et al. (1998). In Onnen et al.(1997) the authors present an algorithm that is a combination of GA and Model Predictive Control (MPC)and explore its behaviour in controlling non-linear processes with model uncertainties.

Research Methodology

This chapter discusses the methodologies used to achieve the objective of this study including the procedures and materials used to conduct the experimental test on the existing used oil fired crucible furnace. The three level and seven factors of design parameters are selected to Predict and verify the improvement of the effective energy utilization. The focus is on systematic and objective investigation of parameters involved in the aluminium melting processes in order to determine the optimum level of the factors for efficient energy utilization

Equipment, Tools and Machines Used in the Experimentation

Equipment, tools and machines used in conducting the experiment consists of: used oil fired crucible furnace with mechanical oscillating valve and standard air blower, fire brick wall, metallic crucible, digital melt-meter with thermocouple, digital camera. As shown in Figure 3.1 in oil fired crucible furnace, used oil filter/riddle is placed on the inlet and out let of container for controlling and filtering any foreign particles that can affect the flow rate burning efficiency of the used oil. The filtered oil with appropriate viscosity is put in a container and further proceeds to the burner nozzle. The used oil container is connected to the oil runner that is connected to the burner nozzle with mechanical adjustable valve to control the flow of oil to the burner; On the other hand, standard adjustable electrical air blower is plugged to the electrical socket and air runner. The oil and air are mixed at 0 - 150mm and it flows to the nozzle burner and changed by atomization to the burner. Burning flame is adjusted for safe operation and optimizes the temperature. 30kg,35kg and 40kg of aluminium scraps charge/placed in the crucible and it uses SAE 15W-40(engine) oil with a viscosity of 900 Centistokes(cSt) before giving service.

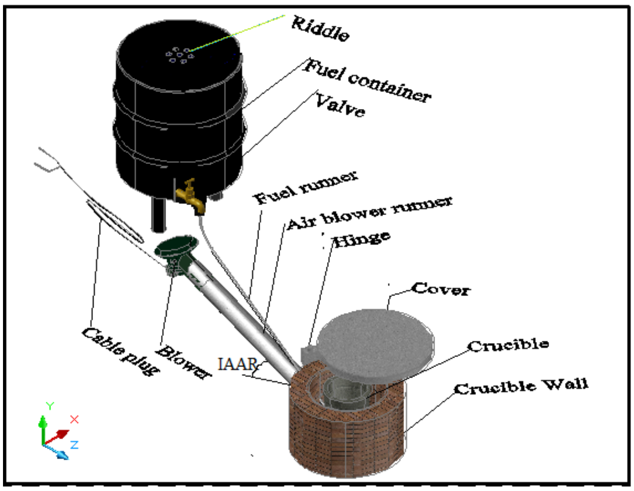


Figure 3.1: Used Oil Fired Crucible Furnace

Source: adopted from SME medebir foundry work shop, (2016).

Throughout the experimentation process, digital Multi meter; figure 3.2 is used as measuring melting temperature using k-type thermocouple.

Figure 3.2: DigitalMillimeter with Thermocouple

Parameter Selection for DOE

Fuel consumption, pollution and melting time of small sized used oil fired crucible furnace temperature for melting Aluminium in local foundry workshops were depend on different parameters. The selection criteria of parameters were based on their effect of the output, parameter selection criteria was prepared and compared among each other using rates 0's (for same), +'s (for better than),-'s (for the worse) relative to the particular criteria, ranked the concepts using the sum of all the "better than", "Same as" and "worse than" and finally the study selected seven parameters Karl T and Steve D. (2000).

Table 3.1 Parameter Selection Screen Matrix Of Used Oil Fired Furnace

Selection criteria	**Parameters**										
	ABR	FDR	CM	IAAR	CWC	PFA	DFAM	ARL	FRL	FROD	IAFR
Greater +ve effect	+	0	+	-	0	0	-	-	-	-	-
Easily measurable	0	0	-	0	0	0	0	0	0	0	0
Experimental cost	+	+	-	+	0	+	+	-	-	-	+
Experimental time	+	+	-	_	0	+	-	_	_	_	_
Controllable/variable parameter	0	0	-	0	0	0	0	0	0	0	0
sum+'s	3	2	1	1	0	2	1	0	0	0	1
sum0's	2	3	0	2	0	2	2	2	2	2	2
sum-'s	0	0	4	2	0	0	2	3	3	3	2
net score	3	2	-3	-1	0	2	-1	-2	-2	-2	-1
Rank	1	2	10	5	4	2	5	6	6	6	5
Continue?	Yes	Yes	No	Yes	Yes	Yes	Yes	No	No	No	Yes

Source: Karl T and Steve D. (2000).

Experimental Procedure

Number of Experiments Conducted and Sample Size

The used oil fired crucible furnace process parameters were the input variables, while the fuel consumption, melting time and pollution level were the output variables of the melting process. Taguchi Robust Design Matrixes for 3*7 L27 orthogonal arrays generated. Table 3.4shows Robust Design Matrix with seven (7) factor, three (3) level and (27) runs. By studying the effect of individual factors on the results, the best factor combination was determined. The combination Design of Experiments with optimization of used oil fired crucible furnace parameters to achieve best results. Table 3.2shows used oil fired crucible furnace parameters and their levels for the DOE based on the seven selected variable parameters. The 27 experiments was designed using DOE tool.

Table 3.2 Variable Parameters of Used Oil Fired Furnace

No.	used oil fired crucible furnace parameters	Factors and their levels for melting aluminium		
		Level 1	Level 2	Level 3
1	Air Blow rate(ABR)	2900rpm	3000rpm	3100rpm
2	Fuel drop rate(FDR)	3ml/sec	3.5 ml/sec	4 ml/sec
3	Inclination angle of fuel runner(IAFR)	35^0	40^0	45^0
4	Inclination angle of air runner(IAAR)	35^0	40^0	45^0
5	Clearance between wall of the furnace and crucible(CWC)	60mm	70mm	80mm
6	Position of fuel and Air mixed (PFA)	At the end (0)	100mm beyond	150mm beyond
7	diameter of fuel and Air mixed orifice(DFAM)	80mm	90mm	100mm

Source: adopted from SME medebir foundry work shop, (2016).

Table 3.3 Constant Parameters of Used Oil Fired Furnace for Melting Aluminium

1	Air Runner length	1250mm	1250mm	1250mm
2	Fuel Runner length	1250mm	1250mm	1250mm
3	Air runner orifice diameter	120mm	120mm	120mm
4	Fuel runner orifice diameter	16mm	16mm	16mm

Source: adopted from SME medebir foundry work shop, (2016).

Table 3.4: Design of Matrix (DOE) for melting 30kg Aluminum Using SAE 40 used oil

No	ABR	FDR	IAFR	IAAR	CWC	PFA	DFAM
1	1	1	1	1	1	1	1
2	1	1	1	1	2	2	2
3	1	1	1	1	3	3	3

No	ABR	FDR	IAFR	IAAR	CWC	PFA	DFAM
4	1	2	2	2	1	1	1
5	1	2	2	2	2	2	2
6	1	2	2	2	3	3	3
7	1	3	3	3	1	1	1
8	1	3	3	3	2	2	2
9	1	3	3	3	3	3	3
10	2	1	2	3	1	2	3
11	2	1	2	3	2	3	1
12	2	1	2	3	3	1	2
13	2	2	3	1	1	2	3
14	2	2	3	1	2	3	1
15	2	2	3	1	3	1	2
16	2	3	1	2	1	2	3
17	2	3	1	2	2	3	1
18	2	3	1	2	3	1	2
19	3	1	3	2	1	3	2
20	3	1	3	2	2	1	3
21	3	1	3	2	3	2	1
22	3	2	1	3	1	3	2
23	3	2	1	3	2	1	3
24	3	2	1	3	3	2	1
25	3	3	2	1	1	3	2

26	3	3	2	1	2	1	3
27	3	3	2	1	3	2	1

Symbol Represented

1= Low level of each parameters used

2= Medium level of each parameters used

3= High level of each Parameters used

Note: input variables on the above tables represents as follows: ABR- air blow rate, FDR-fuel drop rate, IAFR -inclination angle of fuel runner, IAAR -inclination angle of air runner, CWC-clearance between wall of the furnace and crucible, PFA-position of fuel and air mixture and DFAM-diameter of fuel and air mixture.

Results and Discussion Analysis

The effect of various process parameters taken on selected Aluminium ingot as raw material to be melted during experimentation. Throughout the experiment analysis weights of Aluminium sample were 30kg, 35kg and 40kg and type of oil uses SAE 15W-40 (engine oil) with a viscosity of 900 Centistokes(cSt)(before giving service)have been discussed in this chapter. The numbers of experiments were conducted using the l_{27} orthogonal array as described in Table 3.4. The l_{27} orthogonal array with seven factors, three levels and their experimental responses are shown in Table 4.1and it is optimized using genetic algorithm. As the result, validate the optimized value of the used oil fired furnace of this thesis.

Result and Discussion

The numbers of experiments were conducted using the l_{27} orthogonal array based on DOE Table 3.4. With seven factors, three levels and their experimental responses are shown in the Table 4.1The effect of various process parameters taken on selected aluminium scrap to be melt for discussion on this section.

Table 4.1: AverageExperimental Results for Melting 30 Kg Aluminium

No	ABR (Rpm)	FDR (ml/sec)	IAFR (degree)	IAAR (degree)	CWC (mm)	PFA (mm)	DFAM (mm)	FC (liter)
1	2900	3.0	35	35	60	0	80	8
2	2900	3.0	35	35	70	100	90	7.5
3	2900	3.0	35	35	80	150	100	7.9
4	2900	3.5	40	40	60	0	80	9
5	2900	3.5	40	40	70	100	90	8.4
6	2900	3.5	40	40	80	150	100	8.8
7	2900	4.0	45	45	60	0	80	9.95
8	2900	4.0	45	45	70	100	90	9.2

9	2900	4.0	45	45	80	150	100	9.8
10	3000	3.0	40	45	60	100	100	6.85
No	ABR (Rpm)	FDR (ml/sec)	IAFR (degree)	IAAR (degree)	CWC (mm)	PFA (mm)	DFAM (mm)	FC (liter)
11	3000	3.0	40	45	70	150	80	7.1
12	3000	3.0	40	45	80	0	90	7.9
13	3000	3.5	45	35	60	100	100	7.6
14	3000	3.5	45	35	70	150	80	7.9
15	3000	3.5	45	35	80	0	90	8.8
16	3000	4.0	35	40	60	100	100	8.3
17	3000	4.0	35	40	70	150	80	8.75
18	3000	4.0	35	40	80	0	90	9.65
19	3100	3.0	45	35	60	150	90	6.85
20	3100	3.0	45	40	70	0	100	7.2
21	3100	3.0	45	40	80	100	80	6.8
22	3100	3.5	35	45	60	150	90	7.3
23	3100	3.5	35	45	70	0	100	8
24	3100	3.5	35	45	80	100	80	7.4
25	3100	4.0	40	35	60	150	90	8
26	3100	4.0	40	35	70	0	100	8.8
27	3100	4.0	40	35	80	100	80	8.1

Note: input and output variables in Table 4.1represents as follows: FC-fuel consumption ,ABR- air blow rate, FDR-fuel drop rate, IAFR -inclination angle of fuel runner, IAAR -inclination angle of air runner,CWC-clearance between wall of the furnace and crucible, PFA-position of fuel and air mixture and DFAM-diameter of fuel and air mixture.

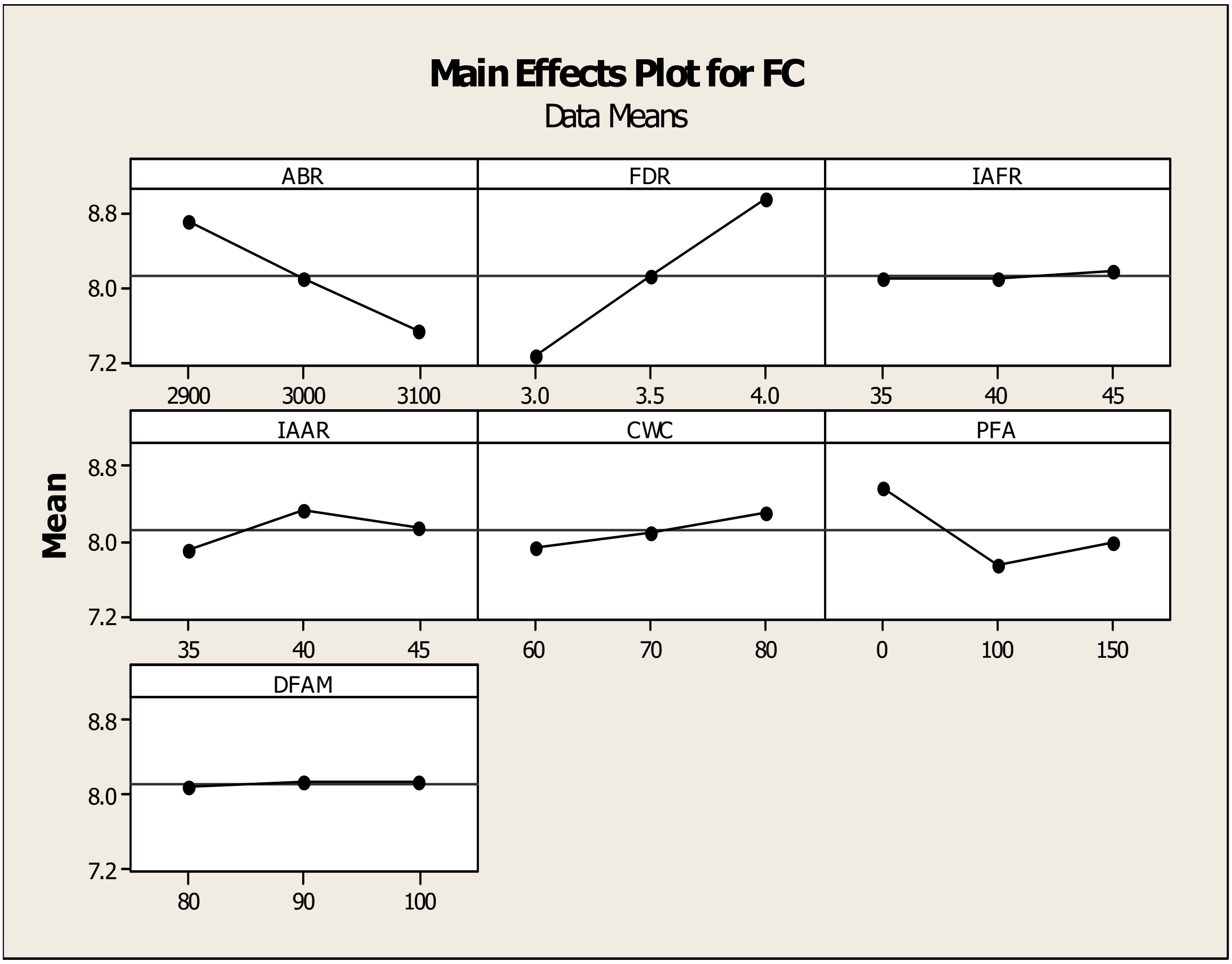


Figure 4.1: Effect of Each Input Parameter vs. Fuel Consumption (30kg)

Table 4.2 Effect of Each Parameter for Melting 30 Kg Aluminium

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**
Regression	7	21.7577	21.7577	3.1082	49.688	0.000000
ABR	1	6.3012	6.2455	6.2455	99.839	0.000000
FDR	1	12.5835	12.4937	12.4937	199.722	0.000000
IAFR	1	0.0313	0.0338	0.0338	0.541	0.471076
IAAR	1	0.0625	0.0186	0.0186	0.297	0.592183

Continued from table 4.2

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CWC	1	0.6603	0.6664	0.6664	10.653	0.004085

PFA	1	2.1101	2.1101	2.1101	33.731	0.000014
DFAM	1	0.0089	0.0089	0.0089	0.142	0.710383
Error	19	1.1886	1.1886	0.0626		
Total	26	22.9463				

Summary of Model

S = 0.250111 R-Sq = 94.82% R-Sq(adj) = 92.91%

PRESS = 2.41139 R-Sq(pred) = 89.49%

Note: input variables in the Table 4.2 represents as follows: ABR- air blow rate, FDR-fuel drop rate, IAFR -inclination angle of fuel runner, IAAR -inclination angle of air runner, CWC-clearance between wall of the furnace and crucible, PFA-position of fuel and air mixture, DFAM-diameter of fuel and air mixture,R-Sq- R-squared,R-Sq(adj), Predicted R^2 ,SeqSS- Sequential sum of squares, Adj SS -Adjusted sum of squares, Adj MS-Adjacent of sum, F-Factor analysis and P-value determines the appropriateness of rejecting the parameter. The experiment of each crucible furnace parameters, the selection is determines the appropriateness of rejecting the parametric contribution based on the p-value is the probability of obtaining a test statistic that is a least as extreme as the calculated value. For this thesis alpha value is 0.05 represent for level of significance. If the p-value of a test statistic that is less than your alpha, your parameters have no greater effect on the output. Based on this principle as the result shows in the above Table 4.2 most of the parameters their p-values are less than the alpha value. Therefore, each parameter has its own significant effect.

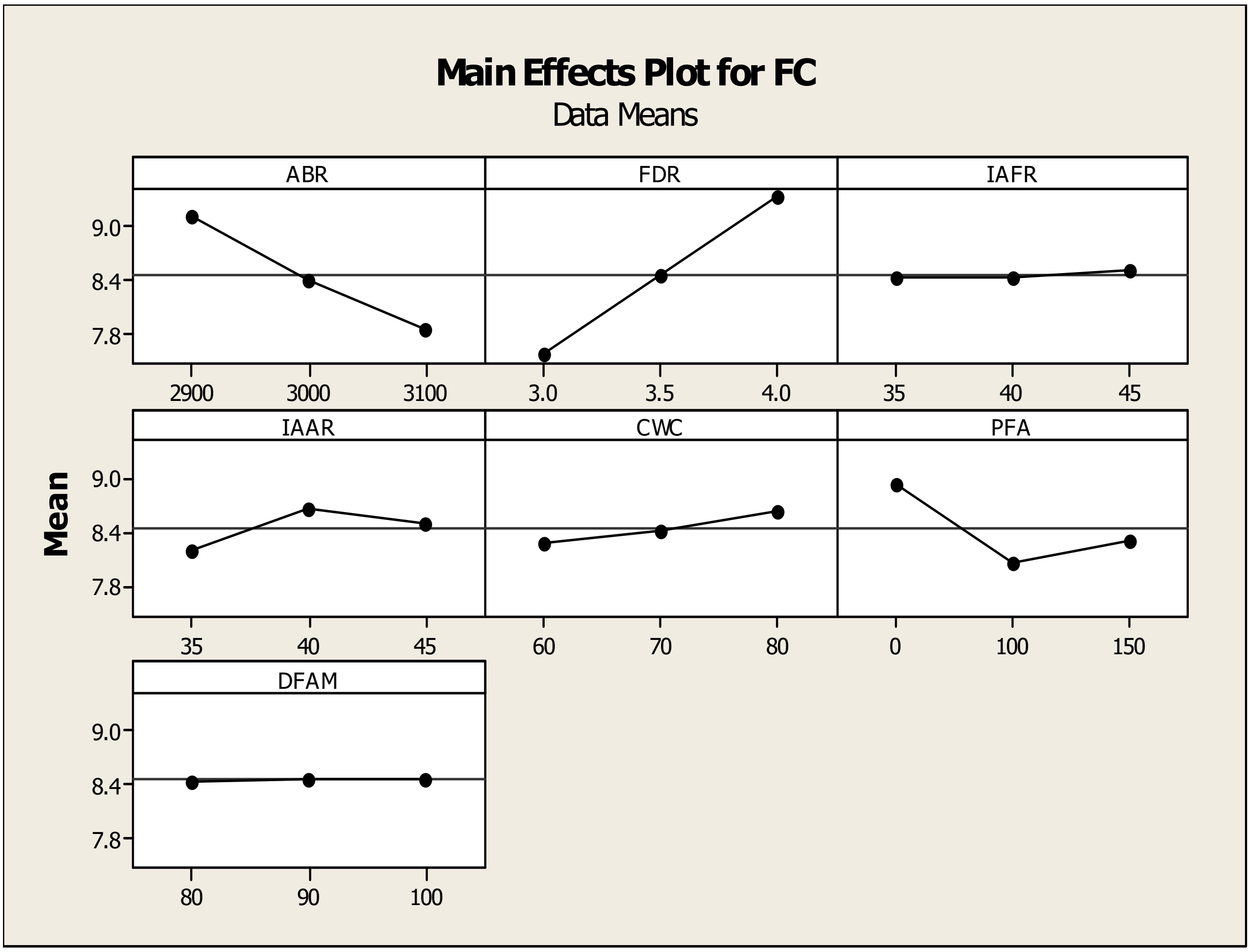


Figure 4.3: Effect of Each Input Parameter on Fuel Consumption (35kg)

Table 4.3: Effect of Each Parameter for Melting 35 Kg Aluminum

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**	**%**
Regression	7	24.1951	24.1951	3.4564	47.081	0.000000	
ABR	1	7.2200	7.1324	7.1324	97.153	0.000000	28
FDR	1	13.8689	13.7360	13.7360	187.102	0.000000	54.2
IAFR	1	0.0356	0.0403	0.0403	0.548	0.468039	0.14
IAAR	1	0.1171	0.0516	0.0516	0.703	0.412305	0.45
CWC	1	0.5603	0.5663	0.5663	7.714	0.012000	2.1

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
PFA	1	2.3898	2.3898	2.3898	32.552	0.000017	9.3
DFAM	1	0.0035	0.0035	0.0035	0.047	0.830156	0.014
Error	19	1.3949	1.3949	0.0734			
Total	26	25.5900					

Summary of Model

S = 0.270952 R-Sq = 94.55% R-Sq(adj) = 92.54%

PRESS = 2.85799 R-Sq(pred) = 88.83%

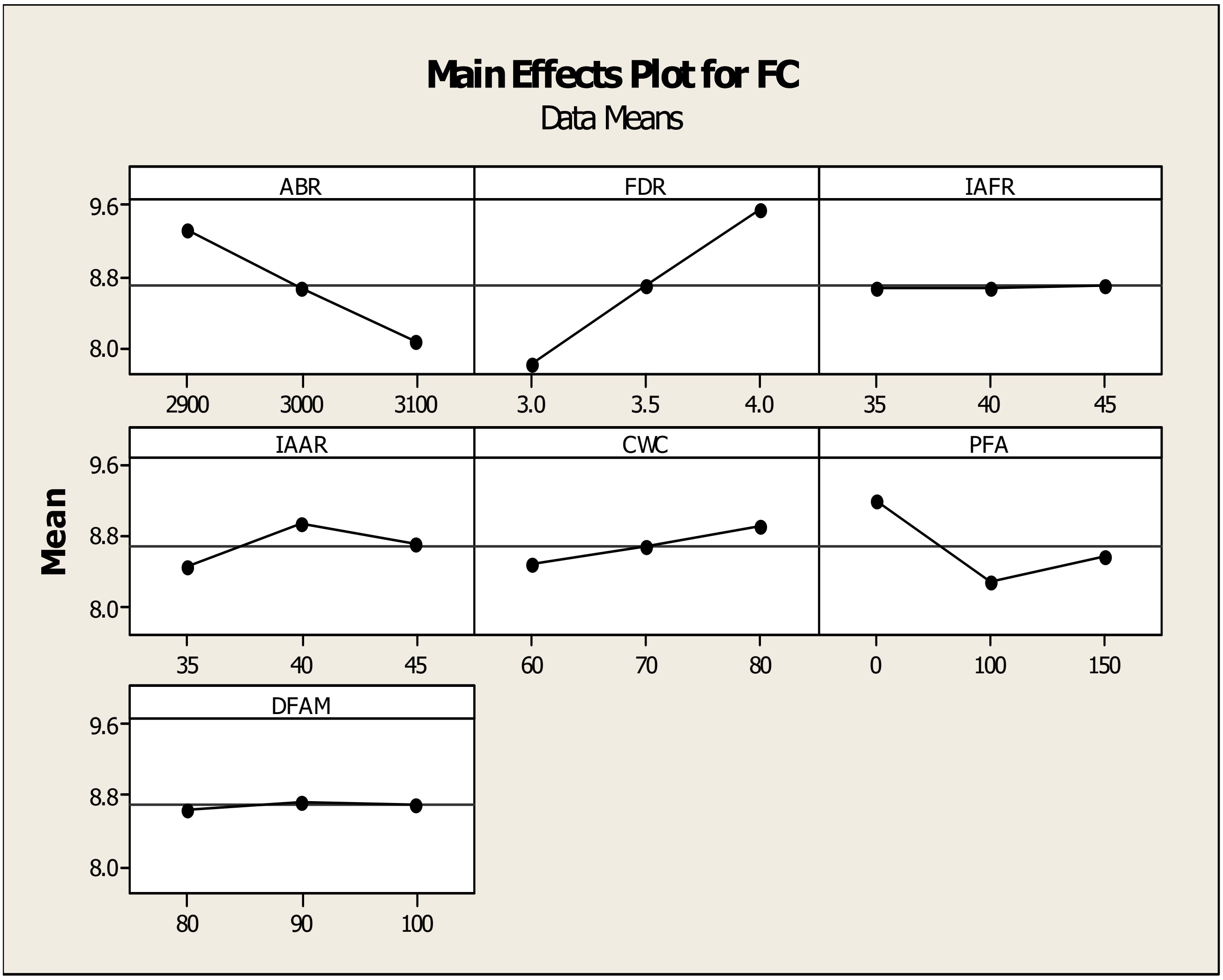


Figure 4.4: Effect of Each Parameter on Fuel Consumption

Table 4.4 Effect of Each Parameter for Melting 40 Kg Aluminum

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**	**%**
Regression	7	24.5018	24.5018	3.5003	43.943	0.000000	
ABR	1	7.2835	7.2279	7.2279	90.741	0.000000	28
FDR	1	13.7813	13.6937	13.6937	171.914	0.000000	53
IAFR	1	0.0050	0.0059	0.0059	0.074	0.788147	0.01
Source	DF	Seq SS	Adj SS	Adj MS	F	P	%
IAAR	1	0.0582	0.0135	0.0135	0.169	0.685672	0.22
CWC	1	0.8235	0.8309	0.8309	10.432	0.004409	3.1
PFA	1	2.5191	2.5191	2.5191	31.625	0.000020	9.7
DFAM	1	0.0313	0.0313	0.0313	0.392	0.538535	0.12

Error	19	1.5134	1.5134	0.0797			
Total	26	26.0152					

Summary of Model

S = 0.282231 R-Sq = 94.18% R-Sq(adj) = 92.04%

PRESS = 3.04597 R-Sq(pred) = 88.29%

Conclusion and Recommendation

Conclusion

Foundry technology mainly requires furnace for melting the metal to be casted. The main problem of the furnace was observed in consistent Efficiency. Hence, the existing furnace needs to optimize efficiency of the furnace. Based on the three specific objectives of this study controlling combination of seven selected input variable parameters was the method to optimize the current status of the furnace efficiency on selected in put parameters. Hence, the existing furnace output parameters were not optimal such as fuel consumption, melting time and pollution while melting. According to the work conducted on the selected seven process parameters, three levels and 27 numbers of experiments on each of the 30kg, 35kg and 40kg of aluminium stock that melts in used oil fired crucible furnace foundry work shop of selected study areas of SME and training institutes. Based on DOE, the experimental result and ANOVA clearly described that, four of the input parameters are the most influential for optimizing the efficiency of the furnace; nearly 53% of fuel drop rate, 28 % of air blow rate, 9% of position of fuel and air mixture and 3% of clearance between wall of the furnace and crucible. Fuel consumption, melting time pollution and quality of castings are the important output parameters affected by the input parameters. The best fitness results to obtain improved efficiency of the furnace using the selected seven parameters (3100.000rpm of ABR, 3.032ml/s of FDR, 35.200degree of IAFR, 35.100 degree of IAAR, 60.09mm of CWC, 8.500mm of PFA 80.050mm of DFAM), `Based on the optimized value and validation, fuel consumption for 30kg,35kg and 40kg of aluminium requires 6.830 litters, 7.014liters and7.120 litters consecutively, the melting time duration observed during validation of optimized value fuel consumption is 38 minute, 40 minute, 41minute consecutively. According to this study up to 54% fuel can be saved and hence, effective combustion will be occurred and pollution will be reduced while melting. Moreover, as the amount of aluminium scrap to be melted increases, efficiency of the furnace increases significantly.

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